FORESTRY ECONOMICS: PRINCIPLES AND PRACTICE

1. INTRODUCTION

A forest has the potential to produce a wide range of goods and services such as lumber, wood pulp, recreation, forage for livestock, habitat for wildlife, flood prevention, reduction of soil erosion and a source of biodiversity, although some of these outputs may be incompatible with others. Forestry is the efficient use of an area of land if the rent generated by the forest is higher than that which could be generated by alternative uses, such as agriculture.The task of forestry economics is to help determine a level and pattern of forest use which maximizes the present value of forest rent. The annual forest rent is the total annual value of the flows of the various goods and services produced by the forest. An optimal pattern of forest exploitation may involve multiple uses of the forest, either simultaneously or sequentially, or it may involve a single use such as logging or recreation. In this paper we will mainly consider two uses: timber production, involving clear-felling an area of forest after a period of several years of growth; and recreation involving annual use of the services of the forest.

As in the case of the fishery, the analysis of the values of alternative uses of the forest is based on a bioeconomic model. The biological component of the model describes the growth of the volume of timber over time on a hectare of forest land. The economic component of the model places dollar values on the output of forested land under alternative patterns of use. These values are obtained by subtracting the cost of a particular use from the market value of the good or service produced. As noted above, some uses, such as recreation, occur more or less continuously, whereas logging occurs intermittently. The values of alternative uses of the forest can be assessed by comparing the present values of alternative flows of goods and services - the site value under alternative uses - or by converting site values to constant annual rental values for comparison.

The net value of the timber growing on an area of forest land is termed the stumpage value - the value of the timber "on the stump". This can be calculated as the competitive sale value of the timber less the cutting and transportation costs. The cutting cycle which maximizes the present value of stumpage is the optimal rotation; this could involve a single harvest from the forest, or a succession of cycles of harvest and regrowth. The present value of stumpage is the value of the forest land in timber production and this value can be compared with its present value in alternative uses.

2. THE BIOECONOMIC MODEL

A bioeconomic model is used to help determine an efficient management plan for the forest. As in the case of the fishery, the model consists of a biological production function combined with an economic model of production and cost. The biological production function describes the relationship between time and the quantity of timber growing on a hectare of forest land. The biological model could be a biomass model, like the logistic or Gompertz model, or it could be a more detailed model describing the experience of a cohort of trees over time. As the forest matures both the species composition and the size composition of individual species may change. These changes may have important implications for the value and the management of the forest; for example, Table 1 shows how the proportion of timber allocated to different commercial uses changes as the age of the stand increases. A detailed forest management plan would need to take account of such changes and the biological model for this purpose would be a computer simulation model of tree growth, such as the STANDSIM ("stand simulator") model developed by the Forest Service in Victoria. A biomass model, such as that illustrated in Figure 1 will be sufficient for our purposes: the volume of timber on a hectare of forest land is assumed to be an increasing function of the age of the stand. Since there is obviously a limit to the quantity of biomass supported by a hectare of land, similar to the environmental carrying capacity in the model of the fishery, the instantaneous growth rate of the volume of timber must decrease after some point in time.

The biological production function can be combined with price and cost information to obtain the stumpage value as a function of the age of the stand of trees. The stumpage value is the value of the timber which can be harvested from the stand. For the moment we will ignore uses of forest land other than timber production. Stumpage can be defined as:

$$S(t) = p(t)x(t) - c(x(t))$$

where p(t) is the market value per unit (the "price") of biomass, x(t) is the quantity of biomass, and c(x(t)) represents the cost of felling a hectare of timber and transporting it to market. As indicated by Table 1, as the stand of timber ages a higher proportion of the timber can be put to higher value uses such as sawmilling. This means that the price per unit of biomass tends to rise as the age of the trees rises. As the age of the stand increases the number of trees is likely to decrease even although the total biomass is increasing. A smaller number of trees is likely to reduce felling costs per hectare, but a larger biomass is likely to increase transportation costs. Thus the combined felling and transportation cost per hectare may rise or fall as the age of the stand increase. However it is likely that the combined effect of rising biomass and rising unit value of biomass will offset any tendency towards rising harvesting costs per hectare. This means that stumpage value per hectare will rise as the age of the stand increases

For simplicity we will assume that the market price of timber per unit of biomass is independent of the age of the stand, and that the felling and transportation cost is constant per hectare. Figure 2(a) shows the market value of timber in the stand as a function of the age of the stand, and the constant harvesting cost per hectare. The stumpage is illustrated in Figure 2(b) where the curve S(t) is obtained by subtracting the felling and transportation cost from the market value of the stand.

3. OPTIMAL ROTATION

The optimal rotation is the age at which the trees should be cut if the objective is to maximize the value of the land - the land rent or site value - in commercial timber production. Of course, commercial timber production may not be the best use of the land; this will be determined by comparing the values of alternative uses. We will calculate the optimal rotation under two assumptions about land use: first, that only the current stand will be harvested, perhaps because of the site`s limited capacity to regenerate; and second, that there will be a perpetual uniform cycle of cutting and regrowth.

3.1 Optimal Rotation - One Harvest

The owner of a one-hectare stand of timber has two principles at her disposal to help determine the age at which she should cut the stand: the static and dynamic efficiency principles. Fortunately application of these two principles gives the same result. Static efficiency requires that marginal benefit is set equal to marginal cost. The marginal benefit of letting the stand grow for an extra period of time is: dS(t)/dt. The marginal cost is the forgone interest which could be earned by cutting the stand now, selling the timber, and placing the proceeds in the bank; the forgone interest is rS(t). Setting marginal benefit equal to marginal cost gives the following rule: keep the standing timber as long as dS(t)/dt > rS(t), or until dS(t)/dt)/S(t) = r. The commonsense of this rule is that you should leave your capital in the forest - the "tree bank" - as long as the rate of growth of value of timber exceeds the rate of growth of the value of assets in the ordinary bank.

The principle of dynamic efficiency says that you should utilize an asset in such a way as to maximize the present value of the goods and services the asset generates over time. The present value of the hectare of forest land, assuming that its only productive use is in growing the current stand of trees, is: $V(t) = S(t)/(1+r)^t$, where t is the age at which the stand is cut. In Figure 3, the present value, V(t), is illustrated as a function of the rotation age; at the maximum point of the V(t) function V(t) = V(t+dt) where dt is a very small increment of time. It is approximately true that, at the optimal rotation, V(t) = V(t+1). This gives the following relation:

$$S(t+1)/(1+r)^{(t+1)} - S(t)/(1+r)^t = 0.$$

This equation can be solved to give: S(t+1) - S(t) = rS(t), or dS(t)/dt = rS(t). The left hand side of this expression is the marginal benefit of letting the trees continue to grow, and the right hand side is the marginal cost. In other words, application of the principle of dynamic efficiency gives us the same rule as we obtained from the principle of static efficiency.

In summary, for a stand of trees which has no alternative use other than the production of timber from a single rotation, the rule for economic efficiency is to cut the trees when the rate of growth of value of timber has fallen to equal the rate of interest. The application of this rule, which was developed by Irving Fisher and is sometimes called `Fisher´s Rule`, is illustrated in Figure 4 which shows three paths to riches: (1) cut the timber now and put the money in the bank; (2) keep the stand of timber no matter what; or (3) maintain the stand of trees as long as the stumpage value is growing faster than the rate of interest, and then shift your assets to the bank. The latter strategy is shown to be the best of the three.

3.2 Optimal Rotation - Multiple Harvests

We now assume that there will be a perpetual cycle of cutting, followed by regrowth, followed by cutting and so on until the end of time. Regeneration of the forest may occur naturally or it may involve site preparation and planting after each harvest. In the latter case the level of harvesting costs in our model will be increased to cover the latter activities. To analyse the optimal rotation in a perpetual cycle we assume that the stumpage value at each age is the same from one rotation to the next. This means that the productivity of the hectare of land is assumed to be unimpaired by producing successive crops of trees and, consequently, that the biological production function does not shift in any way over time. It also means that the economic conditions remain constant: the market price of timber is constant over time, and logging, transportation, and replanting costs remain unchanged. In fact, none of these assumptions is likely to be true: logging tends to cause erosion which reduces the productivity of the site; the real price of timber has been rising steadily over the past 100 years, and technological change has reduced costs. Nevertheless, we will maintain these assumptions in order to make the optimal rotation calculation tractable. Finally, we ignore any risks associated with forest fires, disease and pests.

3.2.1 Discrete Time Analysis

The present value of a perpetual cycle, starting with bare forest land, and cutting and replanting every t years is given by:

$V(t) = S(t)/(1+r)^t + S(t)/(1+r)^{2t} + S(t)/(1+r)^{3t} + S(t)/(1+r)^{4t} + ...$

This expression is a geometric progression which can be summed in the usual way. However we can take a short-cut by rewriting the expression as:

$V(t) = S(t)/(1+r)^t + (1/(1+r)^t))\{S(t)/(1+r)^t + S(t)/(1+r)^{2t} + S(t)/(1+r)^{3t} + ...$

Since the term in the curly brackets is V(t) the present value of all rotations can be written as:

$V(t) = S(t)/(1+r)^t + V(t)/(1+r)^t$

This can be solved to give a simple expression for V(t):

$V(t) = S(t)/((1+r)^t -1)$,

which is the present value of a perpetual stream of payments, S(t), occurring at intervals of t years. This expression for V(t) is a measure of the site value - the present value of the bare hectare of land in timber production.

To find the optimal rotation - the value of *t* which maximizes the present value of timber obtained from the site - we can apply the principle of dynamic efficiency in the same way as in the case of the single rotation. When V(t) is maximized it is aproximately true that:

$V(t+1) - V(t) = 0$.

This means that:

$S(t+1)/((1+r)^{(t+1)} -1) = S(t)/((1+r)^t -1)$, and hence that:

$S(t+1) - S(t) = dS(t)/dt = rS(t)\{1-1/(1+r)^t\}$.

The value of *t* which satisfies the above equation is the optimal rotation. The equation, whether expressed in discrete or contimuous time, is often referred to as the Faustmann formula after the German forester who first proposed it in 1849.

The Faustmann formula, which is a condition for dynamic efficiency, can be rewritten in a way that illustrates the operation of the static efficiency principle:

$dS(t)/dt = rS(t) + r\{S(t)/((1+r)^t - 1)\}$.

The left hand side of this equation is the marginal benefit of leaving the trees to grow for a small extra period of time; the right hand side is the marginal opportunity cost, which consists of the forgone interest on the stumpage value, as in the case of the single rotation, plus the forgone interest on the site value. The intuition of the static efficiency principle is that the owner of the hectare of forest land always has two options - continue to own the land for an extra period (in which case the marginal benefit is dS(t)/dt) or cut the stand (which will yield S(t)), sell the bare forest land (which has a value of $S(t)/((1+r)^t - 1)$), place the proceeds of the sale of timber and land in the bank and earn interest. The interest which could be earned in this way over the next period of time is the marginal opportunity cost of holding the timber and land investment. In Case Study 1 the marginal benefits and costs of retaining a stand of Douglas Fir are calculated from tree growth and timber value data and the optimal rotation is found by identifying the age at which marginal benefit has fallen below marginal cost. One interesting conclusion which can be drawn from Case Study 1 is that the value of a stand of mature trees, S(t), generally substantially outweighs the site value, V(t), which is the value of all future rotations, starting with a bare site. The reason for this is the effect of dicounting over the generally lengthy rotation period.

In the case of a single rotation considered earlier no opportunity cost was ascribed to the land; it was assumed that the only use of the hectare of land was in growing the current stand of trees. Once successive rotations are considered the opportunity cost of the land is its value in producing future rotations. Since the instantaneous growth of young trees is higher than for old trees, it can be expected that the optimal rotation is shorter when additional rotations beyond the current stand are introduced to the calculation.

3.2.2 Continuous Time Analysis

If future values are discounted continuously, rather than annually as in Section 3.2.1, the present value of all future rotations which can be obtained from a bare section of forest land, assuming natural regeneration, is given by:

$$V(t) = S(t)e^{-rt} + S(t)e^{-r2t} + S(t)e^{-r3t} + \ldots\ldots\ldots$$

As before, the sum of this geometric progression could be obtained in the usual way. However, using the approach of Section 3.2.1, it can be noted that:

$$V(t) = S(t)e^{-rt} + V(t)e^{-rt},$$

and, by rearranging, that:

$$V(t) = S(t)/(e^{rt} – 1).$$

Choosing the value of *t* to maximize V(t) gives the continuous time version of the dynamic efficiency rule:

$$dS(t)/dt = rS(t) + rV(t).$$

This rule is similar to that derived for the discrete time analysis: the stand of trees should be left to grow as long as the instantaneous rate of growth of the value of the stumpage is at least as large as the opportunity costs of retaining the stand. The latter consists of the forgone interest on the stumpage value of the current stand, rS(t), and the forgone interest on the value of the site in its best alternative use. The best alternative use is assumed to be forestry – growing a succession of new stands of trees – and hence the site value is V(t) and the forgone interest is rV(t).

If it were assumed that there was an initial planting cost of each stand, the cost of planting each successive stand would be subtracted from the stumpage value of the previous stand. This would obviously affect the length of the optimal rotation. The initial planting cost, however, would not affect the length of the optimal rotation, since it is a constant, but it would affect the economic viability of commencing forestry on the bare site: the present value of all future rotations would need to be higher than the initial planting cost to make forestry worthwhile.

3.3 The Optimal Rotation: a diagrammatic exposition

Figure 5(a) illustrates the relationship between the stumpage value of a stand of trees and their age. As noted in Section 2, and illustrated in Figure 2(b), this relationship is based on the biological production function modified by economic factors such as timber price and harvesting cost. In Figure 5(b) the time derivative of S(t), the value of rS(t), and the value of rV(t) (= $rS(t)/(e^{rt} – 1)$) are drawn as functions of time. The optimal rotation is at t* where dS(t)/dt = rS(t) + rV(t). In Figure 5(c), the instantaneous rate of growth of stumpage, (dS(t)/dt)/S(t), is illustrated, along with the term $r/(1 – e^{-rt})$. It should be noted that the latter term tends to r as t tends to infinity. The two curves intersect twice in the diagram, and the use of the second order condition for a maximum indicates that the optimal rotation is identified by the value of *t* at which the $r/(1 – e^{-rt})$ function cuts the instantaneous rate of growth function from below. Since the value of the $r/(1 – e^{-rt})$ function must always exceed the value of r for any finite value of t, the optimal rotation in the repeated harvests case must be shorter than in the single harvest case where the time to cut the trees is calculated by setting (dS(t)/dt)/S(t) = r.

3.4 The Effect of Changes in Price, Cost, Annual Charges, and the Interest Rate on the Optimal Rotation

In this Section we further develop the optimal rotation analysis of Section 3.2, making use of the definition of the the stumpage value developed in Section 2:

S(t) = px(t) – c

where S(t) is the stumpage value, x(t) is the volume of timber on the stand, p is the market value per unit of timber `on the stump` and c is the unit harvesting and replanting cost. In this analysis we are assuming that the market price per unit of timber and the harvesting cost per unit of land does not vary with the age of the trees. Following Binkley (1987), the condition for determining the optimal rotation can be written as:

$(dx(t)/dt)/(x(t) – (c/p)) = r/(1 – e^{-rt})$.

This expression is identical to that for (dS(t)/dt)/S(t) illustrated in Figure 5(c).

It can be seen from Figure 5(c) that the effect of a rise in the interest rate, which shifts the $r/(1 – e^{-rt})$ function upwards, is to lower the optimal rotation age. A rise in the interest rate discourages investment in all assets, including forests. A shorter rotation age reduces the amount of forest capital because the volume and value of standing timber increases with age, over the relevant time-frame. An increase in harvesting or replanting cost (a rise in c) reduces the value of the denominator in the LHS of the optimal rotation condition, thereby raising the value of the LHS. The effect is to shift upwards the (dS(t)/dt)/S(t) function in Figure 5(c), thereby lengthening the optimal rotation. An increase in timber price has the opposite effect to an increase in harvesting cost. It provides an incentive to harvest the trees earlier because the capital value of the stand has risen, and hence the opportunity cost of continuing to hold capital in that form – the interest which could be earned if the trees were cut and the proceeds placed in the bank – has also risen. The higher annual opportunity cost of holding the stand increases the growth performance required of the stand if it is to be retained, and a higher growth performance can only be obtained from younger trees – lowering the age at which the stand is cut. A decrease in timber price is similar to the effect of imposing an *ad valorem* timber royalty – a royalty calculated as a percentage of the unit stumpage value. Imposing a royalty lengthens the rotation which is optimal from a private viewpoint because it increases the incentive to push costs into the future to reduce their present value. The imposition of a fixed annual charge, such as a fire protection levy, would have no effect on the length of the optimal value because its present value would be a fixed sum to be deducted from the site value. If, however, it exceeded the site value it would render forestry on that site uneconomic.

4. THE NORMAL FOREST AND SUSTAINABLE YIELD

The optimal rotation analysis of Section 3 suggests that an area of forest land should be cut every t^* years where t^* is the optimal rotation. Bearing in mind the considerable capital investment in harvesting, transportation and milling or pulping equipment, not to mention the investment in social infrastructure in remote forest regions, it is clear that obtaining raw material from the forest every t^* years is not likely to be a viable economic strategy for the industry. In practice an area of forest land is cut *every* year and the timber used to supply a continuous flow of material to the mill. Each year's harvest can be cut at the optimal rotation age if the forest is `normal` in the sense that it consists of one stand of each age of tree up to the rotation age. The stand which achieves the rotation age in any given year is cut to provide the timber harvest for that year.

4.1 The Normal Forest and Maximum Sustainable Yield

Suppose that a normal forest is A hectares in extent, and consists of t_r stands of timber, each of area A/t_r hectares, where t_r is the rotation age, and that it contains one stand of timber corresponding to each age class from 1 to t_r. Assuming that the forest area is uniform in terms of its productivity, the volume of timber per hectare on a stand in any year is given by $x(t)$, where $x(t)$ is the biological production function. The volume of timber cut each year is given by:

$$X = (A/t_r)\, x(t_r),$$

which is the volume of timber on the stand which has just reached rotation age.

In order to maximize the volume of timber obtained each year from the forest – the sustainable yield – we choose a value of t to maximize X and obtain the rule:

$$(dx(t)/dt)/x(t)) = 1/t_{msy},$$

where t_{msy} is the rotation age which maximizes the sustainable yield from the normal forest. The rule says that the rotation age should be set where the growth rate of timber equals the reciprocal of the age of the trees. Since we know the biological production function, $x(t)$, which determines timber growth on each hectare of the forest we can work out t_{msy} and, hence, the required number of stands, A/t_{msy}.

The MSY calculation is illustrated in Figure 6, which is similar to Figure 5, except that Figure 6 (a) shows the relationship between timber volume and time (the biological production function illustrated in Figure 1) rather than the stumpage value relationship illustrated in Figure 5 (a). Figure 6(b) illustrates the time derivative of the biological production function, which foresters refer to as the current annual increment (CAI) of volume; in economic parlance, this can be thought of as the marginal product of time given by dx(t)/dt. Figure 6(b) also illustrates the mean annual increment (MAI), which is the average product of time, and which is obtained from Figure 6(a) as the slope of the ray from the origin to the biological production function at the relevant age; MAI is defined as x(t)/t. Because of the relationship between average and marginal values – namely that when the marginal exceeds the average value, the average rises, and *vice versa* – the CAI intersects the MAI at the latter's maximum value. The rotation age at which CAI = MAI is t_{msy}; setting CAI = MAI identifies the age at which the MAI is maximized, and cutting the timber at the maximum MAI maximizes the amount of timber which is obtained from the normal forest each year. In Figure 6(c) the growth rate of volume of timber in the stand, and the reciprocal of the age of the stand, are graphed against the age of the stand. The intersection point of the two functions determines t_{msy}. As in the case of Figure 5(c), there are two intersections and the MSY rotation age occurs where the reciprocal of the age of the stand cuts the growth rate from below.

4.2 Comparing the Maximum Sustainable Yield (MSY) and the Maximum Economic Yield (MEY)

Figures 5(c) and 6(c) can be used to compare the rotation ages corresponding to maximum economic yield (MEY), given by the age *t** which maximizes the net present value of the forest, and that corresponding to MSY. In Figure 7 the two diagrams are superimposed. As shown in Figure 7, the MEY rotation is shorter than the MSY rotation. This is normally what we would expect because the MEY rotation takes account of the time value of money which provides an incentive for earlier cutting. However, recalling that (dS(t)/dt)/S(t) = (dx(t)/dt)/(x(t) – (c/p)), it can be seen from the diagram that by varying c and p the MEY rotation, *t**, can be varied. If the ratio of c/p is made high enough the MEY and MSY rotations can be made to coincide.

The relationship between c,p and r that must be satisfied for the two rotations to coincide is obtained by setting:

$$(dx(t)/dt)/x(t)) = r\{(1- (c/px(t^*))/(1 - e^{-rt^*})\} = 1/t_{msy}$$

Rearranging the latter two parts of the expression gives the requirement:

$$(c/p) = x(t^*)\{ 1 - (1 - e^{-rt^*})/rt_{msy}\}.$$

The relationship between c and p is governed by the requirement that the present value of each rotation must be positive:

$$px(t^*)e^{-rt^*} > c.$$

Substituting this relationship into the previous one gives the following condition for the two rotations to be equal:

$$(1 - e^{-rt^*})(rt_{msy} - 1) < 0.$$

Since $(1 - e^{-rt^*})$ is always positive, $r < 1/t_{msy}$ when the MEY and MSY rotation coincide. Binkley cites the example of *P. patula* pine plantations in Tanzania where at a discount rate of 4% p.a. the MEY rotation is longer than the MSY rotation. This would imply that the MSY rotation was less than 25 years, which is typical of fast growing southern pines or tropical plantations.

4.3 Achieving the Normal Forest

This is a problem similar to that of achieving an optimal fish stock. The virgin biomass is too high from an economic viewpoint: at the environmental carrying capacity, K, there is no net growth of biomass – growth equals decay. The biomass needs to be reduced to some optimal value at which the marginal rate of return on the asset equals the marginal return on the best alternative investment opportunity.

There are two general approaches to getting from the virgin biomass to the optimal stock of timber in the normal forest. Under *area control* an area A/t* is cut each year, where A is the forest area and t* is the optimal rotation. After t* years a normal forest has been created which can be harvested sustainably. The problem with area control is that if all sections of the forest are not equally productive some areas will yield more timber than others. This may cause problem for the timber mills which are looking for a constant rate of throughput. Under *volume control* a volume of timber equal to K/t* - the *annual allowable cut* - is harvested every year, where K is the initial biomass of the forest. After t* years all the original volume of timber has been harvested at a constant annual rate, and a normal forest created. If the original forest consists of trees of mixed ages, with some stands less than fully mature, the volume of timber harvested can be increased over the adjustment period to include any growth of timber which occurs. The annual allowable cut is then: $AAC = x_0/t^* + MAI$, where x_0 is the original volume of timber, which is lower than the environmental carrying capacity, K, t* is the optimal rotation, and MAI is the mean annual increment of the forest over the period from the present to t*. This rule is known as the *Hanzlik Formula*. If the MAI was not harvested the volume of timber in the forest at the end of t* years would exceed the volume in the normal forest.

It was suggested above that achieving a normal forest involves reducing the volume of forest capital from the environmental carrying capacity, K, to a lower level, x*, so that the marginal rate of return on forest capital is the same as that on other assets. Since K>x*, the annual volume of timber harvested during the adjustment phase, K/t*, will exceed the annual volume, x*/t*, obtained from the normal forest. The reduction in annual yield that occurs at the point at which the normal forest is achieved is termed the *fall-down effect*, and it poses problems for the milling industry which seeks a constant flow of timber. This kind of effect is a typical consequence of choosing the most rapid approach path from one equilibrium to the next, and it could be avoided by extending the period of adjustment to the normal forest. The costs of delay in reaching the normal forest would then need to be balanced against the benefit of utilizing the required milling capacity over a longer period of time.

5. TIMBER ALLOCATION

A competitive rental market in forest land would result in the successful bidders adopting the optimal rotation. To see this, suppose that the market rental rate for forest land is \$R per hectare. The present value of the net return to timber growers generated by a hectare of bare forest land is given by:

$$NPV(t) = V(t) – R/r,$$

where $V(t)$ is the present value of all future harvests grown on the land when the rotation age is t, R is the annual rental payable per hectare, and r is the interest rate. Assuming that those renting forest land are profit maximizers, they will choose the value of t to maximize $NPV(t)$. Since R is a constant in this problem, the optimal rotation will be chosen.

In a perfectly competitive market, economic profit is driven to zero: the price of each asset is bid up until it equals the present value of the returns it generates. This means that:

$$NPV(t^*) = V(t^*) – R/t = 0,$$

Where t* is the optimal rotation chosen by the profit-maximizing renter of the land. Hence it follows that:

$$R = rV(t^*).$$

In other words, in a perfectly competitive rental market in forest land, the rental price of land per period will be bid up to equal the rate of return on land from growing timber according to the optimal rotation.

While the competitive allocation process is efficient, the main condition for a competitive market in forest land – that there be many buyers and many sellers - is seldom satisfied. Forest land is often owned by the State; in Australia, for example, 70% of hardwood log supplies come from Crown land. This means that there are few sellers of land or timber. On the demand side, because of the high cost of transporting logs, the market area that can be served by any given area of forest land is limited in extent. Within that area there may be few processors bidding for land or logs; for example, because of scale economies there may be only one pulp mill in a forest region, and perhaps only a few sawmills. In other words, the typical market in forest land or timber consists of a few sellers and a few buyers.

In the absence of competitive markets, how are resource owners to dispose of their product? Governments employ a variety of charges on forest resources in order to capture a return from the exploitation of publicly owned land. Charges can be levied on forest land, on the standing timber, on the harvest, or on the right to the timber; and they can be either value- or volume-based. As noted in Section 3.4 , some types of charges, such as those on the volume or value of timber cut, provide an incentive for the timber cutter to depart from the rotation length which maximizes the site rent. Other types of charges, such as fixed annual rental charges are neutral with respect to the private operator's choice of rotation. The most common type of charge is a royalty levied at some dollar rate per cubic metre of timber removed from the site; for example, this type of charge is used in all the Australian States.

If royalties are to used despite their perverse incentive effect on the rotation length, it is desirable that they are set at a level similar to that which would be generated by a competitive market: first, the State forests are a public resource and on equity grounds it is desirable that the State obtains a fair return; secondly, if private operators pay full market value they will have an incentive to allocate the timber to its highest value use. The normal procedure in setting royalties is to estimate the value of the processed timber – in the form of pulp, lumber, or veneer – and then to subtract the estimated cost of cutting, transporting and processing it. This is not a simple exercise because of difficulties in obtaining commercial information about costs, and the problem of allocating joint costs, such as those associated with road construction and maintenance.

In some jurisdictions, a combination of methods is used to charge for and allocate timber. For example, as described in Case Study 2, the State of Victoria has introduced a system of tradeable timber rights, where the right to cut timber also carries the obligation to pay a royalty at a specified rate. If the royalties were set at levels similar to the competitive market value of timber, the timber rights would not command any price in the private market. It turns out, however, that royalties are currently set at levels only slightly above half of the competitive price.

6. SILVICULTURE

Silviculture is a broad term which describes some degree of `farming` of the forest land. The discussion to this point has largely ignored this approach to forestry, concentrating instead on clearfelling and waiting for the trees to grow to financial maturity before clearfelling again. The optimal rotation model allows for an outlay at the time of harvesting; this could represent the cutting and transportation costs only, or it could include some amount of preparation of the cleared site for the next rotation – silviculture. At some level of silvicultural inputs the nature of forestry shifts from harvesting the `wild` forest to operating a tree plantation.

6.1 Silvicultural Measures

Silvicultural measures can be divided into four main categories – regeneration, thinning, fertilization, and pruning. All are aimed at changing in a beneficial way the biological production function illustrated in Figure 1. Regeneration activities include: site preparation – burning residues, slashing undergrowth, and ploughing; preparation of seeds or seedlings; sowing or planting at some density; an application of fertlizer; and pest control. Regeneration activities are intended to get a stand of the desired species off to a good start in life. Thinning involves removing some of the trees, usually the weaker ones, in order to improve the growth rates of the remainder. With pre-commercial thinning the cut saplings are simply left on the forest floor, whereas with commercial thinning they are removed and sold for some use, such as pulwood, for example. Fertilization usually involves aerial drops of fertilizer at intervals during the stand’s growth. Pruning mainly involves removing any lateral branches which will eventually reduce the quality of a saw-log.

6.2 Evaluating Investments in Silviculture

The effects of silviculture on the growth of the stand of trees are complex and require a detailed simulation version of the biological production function to represent and predict. As noted earlier, an example of such a model is the STANDSIM model developed by the Victorian Forestry Commission. The model is available on a spreadsheet and it simulates the growth of various species under a variety of silvicultural measures, and on sites of various quality. The best known and most widely used growth function produced by the model is that for *eucalyptus regnans*, known as Mountain Ash in Victoria, Tasmanian Oak in Tasmania, and Swamp Gum elsewhere. The STANDSIM model predicts the number and size distribution of trees on a stand after a period of growth under the conditions specified by the analyst.

If the number and size distribution of trees are known at each stage in the life of the stand, the value of the timber on the site can be calculated at each point in time. Harvesting costs can also be calculated and a function relating stumpage value to age of stand, such as that illustrated by Figure 2(b), can be derived. The stumpage value function, together with the amount and timing of expenditures associated with the chosen silvicultural regime, can be used to work out the optimal rotation and to determine the site value corresponding to each regime. The aim of the analysis is to determine the set of silvicultural practices which maximize the value of forest land.

The simulation approach to evaluating silviculture has been widely used. Examples are studies by Galapitage (1989) on Mountain Ash in Victoria, Gerrard *et al.* (1993) on Tasmanian Oak in Tasmania, and Heaps (1985) on Douglas Fir in British Columbia. These studies emphasize the importance of two dimensions of the site: its quality, mainly in terms of the depth of its soil, which is usually represented in the simulation model by the steepness of its slope; and its location, in terms of distance from the sawmill and the consequent cost of transporting the timber. On sites which are not of high quality, or which are moderately remote, investment in silviculture is generally uneconomic. The efficient forestry regime for those sites is generally clearfelling, followed by burning and natural regeneration.

6.3 Selective Logging

When forests consist of stands of similar-aged trees of a single or limited range of species, either as a natural outcome or as a result of silviculture, clearfelling is generally the most efficient harvesting method. However when forests are diverse in terms of species and ages of trees, as in, for example, a tropical forest, selective logging may be efficient. Selective logging involves removing particular trees, leaving the remainder to grow and possibly to be harvested at a later stage. Because it involves less disturbance of the forest ecology, selective logging is conducive to retaining some of the non-timber values of the forest described in the next Section.

The main problem with selective logging is getting access to the site and removing the timber. In contrast to clearfelling, investment in logging loads cannot be justified for selective logging which involves removing only a few trees from each site. The amount of equipment to be transported to the site can vary from an axe or a chainsaw to a portable saw mill. In some parts of Papua New Guinea the components of portable sawmills are carried in by timber workers, assembled on site and used to saw the felled timber into boards which can then be removed manually from the site. Where the logs cannot be processed on site they have to be transported to a sawmill by animal or mechanical power. Horses or elephants can be used, and helicopters may sometimes have a role to play.

7. MULTIPLE USE FORESTS

As noted in Section 1, the forest produces a wide range of outputs besides timber. Some of the non-timber outputs involve consumptive uses, such as hunting or gathering, some involve non-consumptive uses such as hiking or bird watching, and some involve no direct use of the forest at all. Examples of the latter outputs are the contribution of the forest to preventing floods, soil erosion and surface salinity, its role in maintaining biodiversity, and its ability to counter greenhouse gas levels by acting as a carbon sink.

7.1 Non-timber Values of the Forest

The relationship between the level of non-timber benefits generated by the forest and the size of the stock of standing timber, as discussed by Calish *et al.* (1978), is not straightforward. Some consumptive non-timber uses are promoted by a short cutting cycle, and hence a small stock of timber; an example is frequent cutting to provide cleared areas which provide forage for game for hunting. Some non-consumptive uses benefit from a large and mature stock of standing timber; examples are hiking and bird watching which tend to improve in quality the older is the forest, although there are exceptions. Some non-use values are generated as long as the timber stock is growing but cease when the forest reaches maturity; examples are flood control through water absorption and greenhouse gas reduction through fixing carbon. Other non-use values continue to increase as the forest ages; examples are control of soil erosion and surface salinity, and provision of biodiversity. Despite the foregoing, and in the interests of analytical tractability, it is probably reasonable to assume, for the moment, that the value of the annual flow of non-timber services generated by the forest is positively related to the volume of timber and hence to the age of the trees comprising the forest.

7.2 Optimal Forest Use: Static Analysis

Many of the non-timber outputs of the forest are public or semi-public goods. For example, flood control is non-excludable – it is not possible to protect some houses in the valley without also protecting others – and non-rivalrous – one person's consumption of the service does not affect the level of benefits received by others. Forest recreation may be a semi-public good: it is not possible at reasonable cost to exclude people from the forest, but the value of the experience derived by each person may decline as the number of recreationalists increases – a crowding effect. Since forest recreation is generally non-excludable, the owner of the forest cannot charge for the experience and hence cannot derive any benefit from the activity taking place. If the forest has two possible outputs – timber and recreational services – the forest owner has an incentive to consider only the former in planning forest use.

Suppose that the combination of timber volume and recreational days that can be produced by the forest in a year are as illustrated by the production possibilities curve in Figure 8. More recreational days implies less timber harvested and *vice versa*. Also each activity is subject to diminishing returns: the inputs which combine with the fixed forest area produce smaller and smaller increments to output (of timber and recreational days respectively) as the output level rises. This gives rise to the concave-to-the-origin nature of the trade-off between timber and recreational output. Even although they cannot be charged for access, recreationists place a positive value on their activity and are willing to pay a sum of money for units of recreation from the forest; the amount of this sum mainly depends on the recreationists` income levels and the cost of accessing alternative sites. The ratio of the recreationalists` willingness to pay per unit to the price of timber forms a value line in Figure 8; the further this line is from the origin the greater the value of the annual output produced by the forest.

The annual value of the forest is maximized at point E, where the value line is tangent to the production possibilities curve. Point E describes some mix of recreational and timber-getting activities. However, since the private owner of the forest receives no revenue from recreation, he/she maximizes the private value of the forest by producing OF units of timber. No recreational services are supplied, the social value of the forest is less than it could be, but the private value is maximized. This outcome is a consequence of incomplete individual property rights to the forest asset; it is well-known that the private market system does not produce an optimal allocation of resources when there are incomplete property rights, or, put another way, the private market system does not generally supply the optimal quantities of public goods.

It might be objected that the example is unrealistic: who would want to hike in a forest which is being logged? If hiking and logging activities are incompatible to some extent in a particular forest, this can be accommodated in the analysis by drawing the production possibilities curve as convex-to-the-origin, as illustrated in Figure 9. It can now be seen that the annual value of the forest is maximized if it is reserved for hiking activities only. However the private owner's return is still maximized by producing OF units of timber, and that will be the private market outcome. Again the absence of individual property rights has led to a private market outcome which is inefficient from a social point of view.

These examples illustrate the case for public regulation of the use of the forests. Once it is recognized that forests produce public goods and services, as well as timber, it is possible that a well-informed and designed regulatory regime, which is not overly costly, can increase the efficiency of resource allocation.

7.3 Optimal Forest Use: Dynamic Analysis

In the optimal rotation problem discussed in Section 3 the value of the annual service flow generated by the forest in the form of timber growth was balanced against the opportunity cost of holding forest capital, in terms of the forgone rate of return in an alternative investment. The consideration of non-timber values introduces another service flow into the analysis – the annual value of the non-timber services provided by the standing forest. Unlike the service flow represented by timber growth, which rises, peaks and then falls as the timber stock increases, the value of the non-timber service flow, it was assumed in Section 6.1, contimues to increase as long as the timber stock continues to grow. In principle the problem remains the same: determine whether the value of the annual flow of services (now timber and non-timber) obtained from the timber stock is large enough to justify continuing to hold the capital stock in the form of trees. However in the timber-only optimal rotation problem the value of the service flow (the growth in timber) has a maximum value at some finite age of the stand of trees, thereby guaranteeing an interior solution to the maximization problem. Once we add the value of the non-timber services, the total annual service flow may have no maximum value in finite time but may approach some limit from below. In this case, the interior maximum may not be the global maximum; in other words, the option of never cutting the stand may dominate the optimal rotation solution.

In the following discussion we follow the approach of Strang (1983), considering first the single rotation problem and then the optimal rotation problem, starting in both cases with bare forest land. We then consider the optimal rotation problem when there is currently standing timber on the site.

In the single rotation case the static efficiency rule is not to cut the site as long as the value of the service flow exceeds the opportunity cost of the forest capital. In this case there are two components to the service flow: the growth in value of the timber and the annual value of the non-timber benefits. The value of the timber stock (the stumpage) can be assumed to increase with time up to some maximum level, after which it declines to some extent because of the decay of mature trees. The instantanous growth in value of timber is the time derivative of the stumpage function and is illustrated in Figure 10 (a) as $dS(t)/dt$. The opportunity cost of holding forest capital is given by the rate of interest multiplied by the stumpage value, and is illustrated in Figure 10 (a) as $rS(t)$. Finally the value of the service flow, which is related to the volume rather than the value of the timber on the site, is illustrated in Figure 10 (a) as an increasing function of time, F(t), which may be asymptotic to some ultimate value.

According to the static efficiency rule, the optimal time to cut the trees is when:

$dS(t)/dt + F(t) = rS(t)$.

As can be seen from Figure 10 (b) the equality is satisfied in two places: at t_1 and t_2. Using second-order conditions for a maximum, it can be determined that t_1 is the interior maximum, and that t_2 represents a minimum value. However, while t_1 is the optimal time to cut the stand *if the stand is to be cut*, the value of cutting must be compared with the value of never cutting, which is a boundary solution to the problem. As indicated by Figure 10 (b), if the stand is allowed to grow beyond t_1 there is a period of time up until t_2 during which the value of the service flow is lower than the opportunity cost of holding the timber. However after t_2 the value of the service flow once again exceeds the holding cost. Whether the stand should be cut at t_1 or never cut is determined by whether the present value of the losses in the period $t_1 - t_2$ exceeds the present value of the gains after t_2. These gains and losses are illustrated in Figure 10 (b) by the shaded areas.

The effect of introducing the possibility of subsequent rotations into the calculation is to raise the opportunity cost of holding capital from rS(t) to r(S(t) + rV(t)) where V(t) is the value of all future rotations when the rotation age *t* is chosen. The efficiency rule now becomes:

$dS(t)/dt + F(t) = rS(t) + rV(t)$.

This modification shifts upwards the opportunity cost function, as shown by the function represented by a dashed curve in Figure 10 (b), and raises the losses and lowers the gains from never harvesting, as compared with the single rotation case. Of course the present value of the gains from never harvesting could still outweigh the losses.

It can be argued that the analysis of the single and multiple rotation cases, starting on a bare site, misses the point of forest conservation. The relevant question is generally whether a financially mature stand of timber should be cut or left for environmental reasons. In other words, the starting point of the analysis should be at some point into what would be the rotation cycle if cutting is to occur. Figure 11 illustrates the efficiency rule in the multiple rotation case. It represents a case where, for a bare site, the present value of the losses from not cutting at the end of the first rotation exceeds the present value of the gains, and, hence, where the interior maximum t_1 is also the global maximum. Now suppose that we are at year t, some way into the first rotation. If $t < t_1$ we wait until $t = t_1$ when it will be optimal to cut and start the second rotation on the perpetual cycle. However a common situation is where $t > t_1$: the forest has been there for centuries prior to European settlement and it is precisely because of its antiquity that the case for never cutting arises. As t approaches t_2 the present value, at time t, of the losses from never harvesting falls, and the present value of the gains rises. The losses which have occurred between t_1 and t are `sunk` and must be disregarded in making the best decision for the future. If at time t the value of the gains from never cutting exceeds the losses, then the boundary solution dominates the interior solution and the decision is never to cut, even although the stand would have been cut if the decision had been made earlier.

In the above analysis, if a stand is once cut it will be cut perpetually according to the rotation cycle. However a case is sometimes made for preserving a stand of regrowth timber. The analysis can accommodate this case by recognizing that the value of the annual non-timber benefits can change in response to changes in population, per capita incomes, prices of other goods, and tastes. The case is often made that services such as outdoor recreation experiences have a high income elasticity of demand; this means that as a person's income rises he/she spends a higher proportion of income on outdoor recreation. As per capita incomes rise the demand for outdoor recreation increases and, given the limited number of available sites, the willingness to pay for a particular site increases. This has the effect of shifting the F(t) function upwards thereby strengthening the case for conservation. The F(t) curve could shift upwards in a way that made a previously logged forest a candidate for conservation.

A final comment about the nature of the F(t) function concerns the assumption that annual non-timber values increase with timber volume and that volume continually increases towards some limiting value (even although stumpage value peaks because of timber quality factors). In their natural state forests go through long cycles of renewal and decay, with wildfires often part of the process, especially in Australia. It is likely that the conservation value of a forest would change significantly over this long cycle and that the decision on whether to cut might have to be revisted from time to time. For example, as noted by Walsh (1995, p. 208), a 400 year old stand of Tasmanian Oak in the southern forest of Tasmania was quarantined from logging after the completion of the Helsham Inquiry. Foresters reported that the trees had a lifespan of 500 years, did not produce much seed in the last 100 years and would not regenerate without fire. Would a sensible management plan for this stand rule out logging for all time?

8. CONCLUSION

This review has discussed bioeconomic models of the forest and used them to explore some policy options for forest management. The main type of bioeconomic model used was based on a biomass model of the growth of the forest, similar to the biomass model widely used in fishery economics. However a more detailed model, similar to the cohort-based models of fish stocks, which simulates the growth of subsections of the forest was also referred to. The bioeconomic models are based on simple assumptions about prices and costs – mainly that the forest industry, as a small part of the economy, is a price taker in both output and input markets.

The models were initially used to examine the harvesting policy which would maximize the net present value of the timber produced by the forest. However it was recognized that non-timber values are becoming increasingly important and must be accounted for in the development of an optimal forest strategy. The various types of non-timber benefits were briefly outlined, and the ability of the forest to generate these at different stages in its development was discussed. The options of altering rotation ages, or of never cutting the forest, in order to increase the flow of non-timber values were explored. The Case Studies consider some of the issues raised in the paper in greater detail.

LIST OF CASE STUDIES

Case Study 1: Calculating the Optimal Rotation for a Stand of Douglas Fir

Case Study 2: Pricing Logs in Victoria: the case of East Gippsland

Case Study 3: Managing Forests for Water Production: the Tarago Catchment Area

Case Study 4: Non-timber Values and the Optimal Rotation: the Eden Management Area in NSW

Case Study 5: Non-timber Values and the Optimal Rotation: the southern forests in Tasmania

CASE STUDY 1

CALCULATING THE OPTIMAL ROTATION FOR A STAND OF DOUGLAS FIR

The optimal rotation problem in the discrete time case was discussed in Section 3.2.1. The information required to calculate the optimal rotation consists of the stumpage value as a function of time, S(t), and the rate of interest. Pearse (1990) reports stumpage values per hectare for Douglas Fir (sold as `Oregon` in Australia) growing in coastal British Columbia. Column 2 of Table 2 shows the volume of timber at each five-year interval in the age of the stand (extrapolated between ages 55 and 60), Column 2 reports the unit value, net of harvesting cost, and Column 3, which is the product of Columns 1 and 2, reports the stumpage value, S(t). When this information is entered in a spreadsheet, it is easy to conduct the following operations required to calculate the optimal rotation: calculate dS(t)/dt as the average annual increment in value in each five-year time period; calculate rS(t) as the rate of interest (5%) multiplied by the stumpage value; calculate the site value, V(t), for each age of the stand (using five-year intervals), given by $S(t)/\{(1.05^t - 1\}$; and, finally, calculate the forgone interest on the site value, rV(t). These values are reported in Columns 5-8 of Table 2. Column 9, which is the sum of Columns 6 and 8, reports the approximate annual opportunity cost of holding the stand of timber for each five-year period, assuming that the timber is at rotation age. By inspection it can be seen that the annual growth in value of the timber exceeds the annual holding cost over the first 55 years of the life of the stand. However it can be calculated by extrapolation that the annual growth in the 57th year is just sufficient, but in the 58th year insufficient, to meet the average annual holding cost. This means that the optimal rotation is 57 years.

At the optimal rotation the value of the standing timber is $12,454 and the bare site value is $823. This difference illustrates the force of discounting, even at a low interest rate, over a long period of time. Since the value of the standing timber dominates the bare site value, the results suggest that for slow-growing trees the Faustmann and Fisher Rules will give very similar answers. In fact the Fisher rotation calculated by extrapolation is 59 years.

CASE STUDY 2

PRICING LOGS IN VICTORIA: THE CASE OF EAST GIPPSLAND

State forest agencies supply about 70% of domestically produced hardwood logs in Australia, with private forest owners providing the remainder. There are two main arguments in favour of setting the price of logs at a competitive level: the first is equity-based – the State forests are a publically-owned resource which should be managed for the public benefit; the second argument is efficiency based – if logs are priced at less than their competitive market value, then whatever system is used to channel them to processors may not succeed in allocating them to their highest value use.

Because State agencies supply such a large proportion of the hardwood log supply they tend to influence the price of logs, with the price received by private producers being closely related to the price set by the State. On the demand side, the East Gippsland area has around twenty small sawmills which, because of the relative isolation of the area and high transport costs, are dependent on locally grown logs. In principle the State forest agency tries to set a competitive market price given by the value of the timber at market less any processing, transportation and cutting costs. However political factors tend to operate to restrain royalty increases, with the result that logs tend to be under-priced.

Following the introduction of transferable log licences in Victoria, O'Regan and Bhati (1991) conducted an assessment of the market values of transferable quotas. Data were collected from a number of hardwood sawmills in East Gippsland which had bought or sold licences in the three years following the introduction of transferable quotas. Licences generally confer timber rights over a period of years, and the prices paid for the licences were converted to a present value per cubic metre using a range of discount rates. Since a royalty is payable on the timber cut, the licence price is a measure of the extent to which the royalty falls short of a competitive market price of timber. Table 3 reports the 1989-90 log royalty rates per cubic metre for various grades of timber, together with the implied quota licence price per cubic metre, calculated using a 4% real rate of interest.

It can be seen from the values reported in Table 3 that the 1989-90 log royalty rates were only in the range 60-80% of the competitive market price of timber. In other words, in the absence of the transferable quota system, log processors were paying well below market value for logs, with the consequent potential for logs not to be allocated to the highest value use.

CASE STUDY 3

MANAGING FORESTS FOR WATER PRODUCTION: THE TARAGO CATCHMENT AREA

The Tarago Catchment area consists primarily of Mountain Ash forest which is managed by the government of Victoria. Half of Melbourne's water catchment area consists of Mountain Ash forests which provide 80% of the total streamflow. Streamflow form the Tarago catchment area feeds the Tarago Reservoir which is used to supply water for irrigation and domestic consumption purposes. Various forestry related factors, such as roading, timber cutting and forest regeneration, affect both the yield of water obtained from the catchment area and its quality in terms of the amount of suspended solids it contains. A study by O`Shaughnessy and Jayasuriya (1991) analyses a management plan which maximizes the sum of the values of timber and water supply benefits.

Streamflow yield is affected by both the age and density of forest stands. Young Ash trees absorb little water, but as their age increases to around 25 years their demand for water also increases. This high level of demand continues until around the age of 40 years. After than age the slower growth of timber makes smaller and smaller demands on the available water and by the time the trees are mature their rate of water absorption is similar ot hat of young trees. Water yields are inversely related to the trees` water absorption rates: yields, measured in megalitres per hectare per annum, vary from 12 in the early stages the life of the timber stand, to around 7 in the intermediate phase, and then eventually rising to 12 again as the forest reaches its maximum volume.

To determine an optimal rotation information on timber growth and water yield is combined with estimates of the value of timber and water production. Victorian state royalties are used to value the timber produced; these may be an under-estimate of the value of the timber (see Case Study 2), but, on the other hand, no allowance is made for annual management costs which would affect the net value of the forest, although, if constant, not the length of the optimal rotation. Water is valued at the price charged by the Melbourne Metropolitan Water Board. When the rotation age is chosen the 1630 hectares of productive Ash forest in the catchment area is treated as if it were a normal forest, and the value of the annual yield calculated.

Two rotation ages are considered: 80 and 150 years. At an 80 year rotation the value of the annual timber production is \$0.58 million and the value of the annual water production is \$2 million; at a 150 year rotation the annual values are \$0.35 million and \$2.4 million, respectively. The combined annual value of timber and water production is \$2.58 million for the 80 year rotation and \$2.75 million for the 150 year rotatation. In selecting the 150 year over the 80 year rotation, \$0.23 million worth of timber is forgone annually to get an extra \$0.4 million dollars worth of water per year.

The only non-timber value considered in the study is water production. The likely existence of other non-timber values which are positively related to the age of the stand, such as prevention of soil erosion, and generation of recreational and aesthetic values would also favour the longer rotation. Even considering only water production, at the optimal rotation the non-timber value of the forest dominates the timber value by a factor of over six to one. The Case Study illustrates the economic importance of non-timber benefits in obtaining maximum value form the forest.

CASE STUDY 4

NON-TIMBER VALUES AND THE OPTIMAL ROTATION: THE EDEN MANAGEMENT AREA IN NSW

The Eden Management Area (EMA), in the south-east corner of New South Wales, consists of three quarters of a million hectares of forest, of which 30% is State forest, 40% is privately owned, and the balance consists of proposed or existing national parks and forest reserves. The area supports a wide variety of plant and animla life, including several species that have been recognized as threatened or endangered. Hartley (1995) analyses the decision of when or whether to cut such areas of old-growth forest. Old-growth forests are identified by the New South Wales State Forestry Commission (State Forests) as areas that are both negligibly disturbed and ecologically mature and have high conservation and intangible values.

Currently State Forests allow timber to be harvested according to an optimal rotation strategy of the kind described in Section 3 above. The rotation period is stated to be 40 years, but, in fact, half the usable timber in each 50 hectare coupe is harvested at intervals of around 20 years. It is believed that by leaving select trees the area is better able to recover from the effects of logging; for example, the remaining trees seed new trees which replace those that were cut. From an optimal rotation calculation, incorporating timber values only, Hartley arrives at a rotation period of 20-25 years for the major tree species.

Hartley introduces three types of non-timber benefits to the optimal rotation calculation: soil erosion prevention; aesthetic value; tourism value; and existence value. The values of the soil erosion and tourism benefits are assumed to be unrelated to the age of the stand of trees, whereas the aesthetic value is assumed to increase with the volume of timber, and the existence value with the age of the stand. Hartley cautions that these types of benefits represent only a fraction of the actual number of positive externalities generated by old growth forests in the EMA.

Hartley applies the analysis outlined by Strang to determine the non-timber value which must be assigned to old growth forest at or beyond maturity (the optimal rotation taking timber values only into account) to make it optimal never to harvest. He finds that an annual non-timber value of $237 per hectare at maturity is sufficient to obtain the `never harvest` result; this result depends on the assumption that the timber values start to decline after maturity and, hence, can never outweigh a constant or increasing non-timber value in the future. In fact the assumed decline in timber values is such that for a forest 10 years in excess of maturity annual non-timber values of only $33 per hectare are sufficient to justify never cutting the stand. For stands currently at maturity, non-timber values less than $237 per hectare are not sufficient to produce the `never harvest` result, but they do lengthen the optimal rotation above the current age of maturity.

CASE STUDY 5

NON-TIMBER VALUES AND THE OPTIMAL ROTATION: THE SOUTHERN FORESTS IN TASMANIA

As illustrated by Case Studies 3 and 4, non-timber values are difficult to measure. An alternative approach, considered in Case Study 4, is to calculate what level and time path of non-timber benefits would the forest need to produce in order to justify never harvesting the trees. In Case Study 5, this approach is applied to a stand of *E. obliqua* (known as Stringybark) in the southern forests of Tasmania. The approach has been used elsewhere in Tasmania, in relation to the proposed Gordon-below-Franklin dam; a study by Saddler et al. (1980) estimated what the value of the annual benefits from the Franklin River area would need to be to render the dam uneconomic from a social viewpoint.

Table 3 shows age and stumpage value data for a stand of Stringybark in the southern forests of Tasmania. Columns 1-8 of the Table are devoted to the optimal rotation calculation, taking timber values only into account, similar to that discussed in Case Study 1. Since the age data are for intervals of 2-5 years, the benefits and costs of holding the stand for an extra period of time are expressed in terms of the present value for the next interval of time. It can be seen from the Table that the growth in value of the stand from age 40-45 is insufficient to meet the opportunity cost of the standing timber and the site, and, consequently, the net benefit value reported in Column 8 for that timeinterval is negative. Hence the optimal rotation is 40 years, and the value of the bare site, using the optimal rotation, and with the interest rate set at 5%, is $342.

In column 9 of the Table the value of the standing timber plus site is reported. The site value is always that calculated for the optimal rotation, since it is assumed that if the timber is cut an optimal rotation cycle will then be followed. The value of the standing timber increases, however, because of increases in volume (not shown) and increases in unit value, as reported in Column 2. The increases in unit value result from the changing composition of the size of trees in the stand, similar to that illustrated in Table 1. It can be seen from Column 9 that the value of the stand plus site continuously increases up to the maximum age reported in the Table. This means that the forest is becoming more valuable over this period and that the opportunity cost of not cutting it is rising.

The Table reports three sets of calculations of present value of non-timber benefits. Column 10 reports the value of non-timber benefits in each time interval when these benefits are assumed to be a linear function of the value of the stand. Column 11 reports the present value of non-timber benefits, assuming the forest is never cut, and assuming that the value of non-timber benefits is constant at the 120-125 age level from age 125 onwards. Columns 12 and 13 report the equivalent values of the assumption that the value of non-timber benefits is assumed to be a linear function of the volume of timber in the stand; and Columns 14 and 15 are based on the assumption that the value of non-timber benefits is linearly related to the age of the stand.

To decide whether the stand should be cut we compare the present value of the timber benefits at each age of the stand with the present value of the non-timber benefits. As long as the latter exceeds the former, the environmental value of the forest exceeds its timber value. By construction, the values of the non-timber benefits are set to give the result, in each case, that the forest should not be cut in the 120 year period considered. The values of the coefficients in the linear relationships are denoted by a in Columns 10, 12, and 14; for example, in Column 10 the annual value of the non-timber benefit is assumed to be 5.1% of the value of the standing timber. However if the value of the standing timber contimued to increase beyond age 120, then the calculations would indicate that the stand should be cut at some point, and if the a values were reduced, then the calculations would indicate that the maximum value could be obtained from the forest by cutting prior to age 120 years. This result can be constrasted with that of Hartley who assumed that the value of the standing timber starts to decline after maturity because of decay.

The solutions obtained from the data and calculations reported in Table 3 are interior maxima. If the timber value data could be reported for ages exceeding 120 years, it is likely that at some point the value of the timber would decline, as suggested by Hartley. Even although the proportion of large trees, which normally provide the most valuable timber, might continue to increase, a greater and greater proportion of these would be damaged by rot and would be classified as pulpwood or waste. If the value of the standing timber function peaked sometime after age 120, and then started to decline because of declining log quality, it is possible that the present value of the non-timber benefits, where these are related to volume or age of timber, could once again come to exceed the value of the stand and site as a source of timber. This would be an example of a boundary solution dominating an interior solution.

The example suggests that if non-timber benefits are to dominate timber benefits they must be related to something other than the commercial value of the timber in the stand, such as, perhaps to timber volume or age. It seems reasonable to suppose that non-timber benefits would not be affected by factors influencing commercial value; for example, the value of the forest as a habitat for birds increases as the number of nesting sites in hollow stumps increases. However if the natural cycle of the forest is growth, decay, and perhaps fire, over a long period of time – perhaps 500 years in the case of Tasmanian oak as suggested in Section 6.3 - it may not be reasonable to assume that non-timber values continually increase with age. The optimal cutting age, taking both timber and non-timber benefits into account, might then involve a very long rotation, perhaps hundreds of years, on sites of high environmental value.

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Table 1 Proportion of Merchantable Timber Volume in Regrowth Eucalypt Forest

Diameter at Breast Height over Bark (DBHOB) (cms)	Proportion of Sawlog	Stand Used Pulpwood	Allocated to Waste
<20	0	0	1
20-39	0	0.93	0.07
40-49	0.32	0.61	0.07
50-59	0.46	0.47	0.07
60-	0.60	0.33	0.07

Source: West and Podger (1980), Table 4.

Table 2 Optimal Rotation for a Stand of Douglas Fir

1	2	3	4	5	6	7	8	9
Age	Volume/ ha	Value/Cu Metre	Stumpage/ ha	Change in Stumpage/ ha	Interest on Stumpage	Site Value	Interest on Site Value	Annual Opport. Cost
Years	Cu Metres	$	$	$/Yr	$/Yr	$	$/Yr	$/Yr
10	2.0	0.0	0.0					
15	14.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	51.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	124.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30	232.0	2.0	464.0	92.8	23.2	139.7	7.0	30.2
35	366.0	4.0	1464.0	200.0	73.2	324.2	16.2	89.4
40	513.0	6.0	3078.0	322.8	153.9	509.6	25.5	179.4
45	662.0	8.0	5296.0	443.6	264.8	663.2	33.2	298.0
50	802.0	10.0	8020.0	544.8	401.0	766.2	38.3	439.3
55	929.0	12.0	11148.0	625.6	557.4	817.6	40.9	598.3
56	951.0	12.4	11792.4	644.4	589.6	820.8	41.0	630.7
57	973.0	12.8	12454.4	662.0	622.7	822.8	41.1	663.9
58	995.0	13.2	13134.0	679.6	656.7	823.8	41.2	697.9
59	1017.0	13.6	13831.2	697.2	691.6	823.8	41.2	732.7
60	1039.0	14.0	14546.0	714.8	727.3	822.8	41.1	768.4
65	1132.0	16.0	18112.0	713.2	905.6	793.0	39.6	945.2
70	1209.0	18.0	21762.0	730.0	1088.1	739.5	37.0	1125.1
75	1271.0	20.0	25420.0	731.6	1271.0	671.9	33.6	1304.6

Key: (1) - (3): Source Pearse (1990)
(4) = (2)*(3)
(5) = (4(t)) - (4(t-1))
(6) = (4)*0.05
(7) = (4)/(1.05**(1) - 1)
(8) = (7)*0.05
(9) = (8) + (6)

Table 3 Summary of Log Royalty Rates and Licence Prices in Victoria

Hard wood Sawlog Grade of Value	**Log Royalty 1989-90 $ per cubic metre**	**Average Quota Price $ per cubic metre**	**Royalty as a Percent Percent**
Low	8.65	5.26	62
Medium	23.03	7.82	75
High	36.43	9.80	79

Source: O'Regan and Bhati (1991)

Table 4 When to Cut the Forest taking Timber and Non-Timber Benefits into Account

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Age	**Price per cubic metre**	**Stumpage Value S(t)**	**Change in Stumpage Value**	**Opport. Cost of Stumpage Value**	**Site Value**	**Opport. Cost of Site Value**	**Net Benefit from Holding Asset**	**PV of Standing Forest and Site**	**Environ. Benefit (Value Based) a=0.051**	**PV Environ. Benefit r=0.05**	**Environ. Benefit (Volume Based) a=1.05**	**PV Environ. Benefit r = 0.05**	**Environ. Benefit (Age Based) a = 5.5**	**PV Environ. Benefit r = 0.05**
Years	**$**	**$**	**$**	**$**	**$**	**$**	**$**	**$**	**$**	**$**	**$**	**$**	**$**	**$**
28	13.8	765.9			262.3									
30	13.8	943.3	177.4	78.5	283.9	26.9	72.0	1285.2	218.7	3409.4	327.4	4278.8	750.1	5523.0
35	14.0	1451.4	508.1	260.6	321.4	78.4	169.1	1793.3	336.5	4072.2	496.4	5043.1	875.1	6091.5
40	14.6	2065.5	614.1	401.0	342.0	88.8	124.3	2407.5	478.9	4767.8	674.5	5802.8	1000.1	6657.6
45	15.2	2709.3	643.8	570.7	339.3	94.5	-21.3	3051.3	628.1	5473.9	849.2	6545.3	1125.1	7220.6
50	15.8	3387.7	678.3	748.5	323.6	93.7	-163.9	3729.6	785.4	6184.6	1026.2	7269.8	1250.1	7779.6
55	15.9	4002.5	614.9	935.9	293.5	89.4	-410.5	4344.5	928.0	6890.9	1201.4	7968.6	1375.2	8333.4
60	16.8	4828.2	825.6	1105.8	273.1	81.1	-361.3	5170.1	1119.4	7610.4	1370.9	8636.8	1500.2	8880.7
65	17.0	5465.0	636.8	1333.9	239.3	75.5	-772.6	5806.9	1267.0	8284.3	1534.6	9273.3	1625.2	9419.6
70	17.9	6338.7	873.7	1509.9	215.4	66.1	-702.3	6680.6	1469.6	8956.1	1692.6	9876.8	1750.2	9947.9
75	17.4	6718.0	379.4	1751.3	177.6	59.5	-1431.4	7060.0	1557.5	9554.9	1846.3	10445.4	1875.2	10462.6
80	18.0	7536.7	818.7	1856.1	155.2	49.1	-1086.4	7878.7	1747.3	10206.9	1994.7	10974.8	2000.2	10959.9
85	18.5	8281.5	744.8	2082.3	133.0	42.9	-1380.4	8623.4	1920.0	10796.8	2135.6	11461.1	2125.2	11435.1
90	19.0	9028.9	747.5	2288.0	113.2	36.8	-1577.3	9370.9	2093.3	11329.3	2270.3	11902.0	2250.2	11882.0
95	18.3	9215.8	186.8	2494.5	90.3	31.3	-2339.0	9557.7	2136.6	11787.7	2399.5	12292.8	2375.3	12292.8
100	19.7	10412.4	1196.7	2546.1	79.8	25.0	-1374.4	10754.4	2414.1	12317.5	2523.1	12626.6	2500.3	12657.6
105	19.9	11006.5	594.1	2876.8	66.0	22.0	-2304.7	11348.5	2551.8	12639.6	2640.8	12894.9	2625.3	12963.6
110	19.8	11397.4	390.9	3040.9	53.5	18.2	-2668.3	11739.4	2642.4	12874.9	2754.3	13087.1	2750.3	13194.5
115	19.5	11713.1	315.7	3148.9	43.0	14.8	-2848.0	12055.0	2715.6	13059.5	2861.7	13187.6	2875.3	13329.8
120	20.6	12804.3	1091.2	3236.1	36.8	11.9	-2156.8	13146.2	2968.6	13201.7	2963.4	13178.8	3000.3	13342.9
									13060.4		13037.6		13200.0	

Notes: (4) S(t) - S(t-1)
(5) S(t-1)((1+r)5 - 1)
(6) S(t)((1+r)t - 1)
(7) ((1+r)5 - 1)S(t)((1+r)t - 1)
(8) (4) - (5) - (7)
(9) (3) + Max((6))
(10) (S(t)/r)*(1+r - (1/(1+r)4))*a
(11) NPV(t) Column (10)
(12) (((3)/(2))/r)*(1+ r + (1/(1+r)4))*a
(13) NPV(t) Column (12)
(14) ((1)/r)*(1 + r + (1/(1+r)4))*a
(15) NPV(t) Column (14)

Figure 1: Volume of Timber on a Stand in Relation To the Age of the Trees

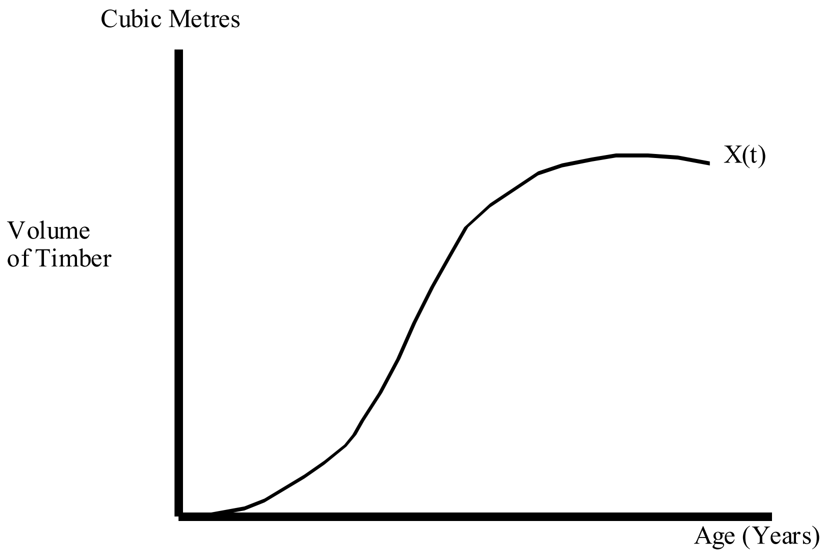


Figure 2: Value of Timber and Harvesting Cost in Relation to Stand Age

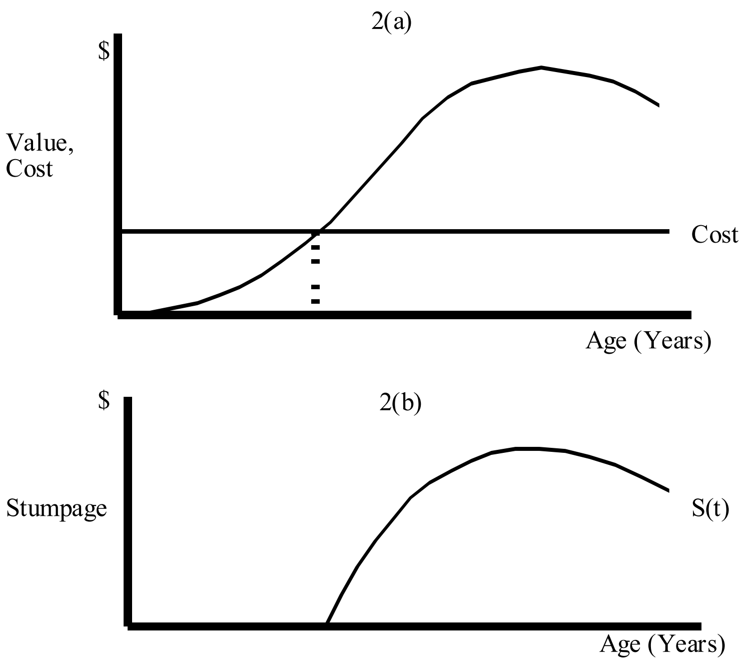


Figure 3: Present Value of Stumpage in Relation to Stand Age

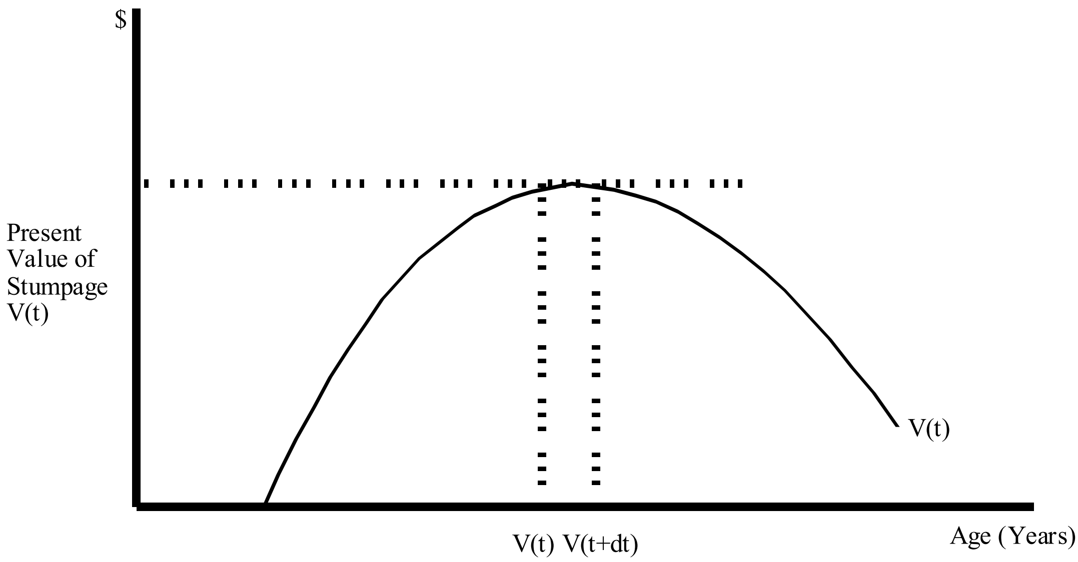
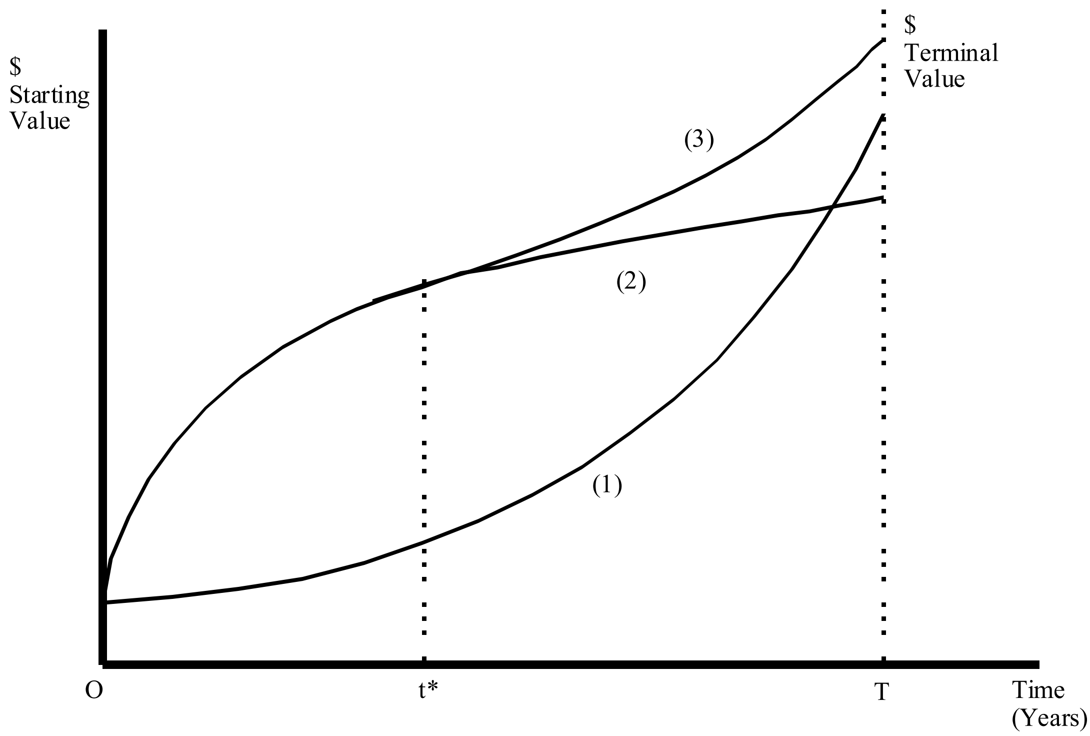


Figure 4: Growth in Asset Values over Time



(1) cut the treest immediately and put the money in the bank (2) let the trees grow until T and then cut and sell (3) let the trees grow until t*, cut, sell and put the money in the bank

Figure 5: Calculating the Optimal Rotation

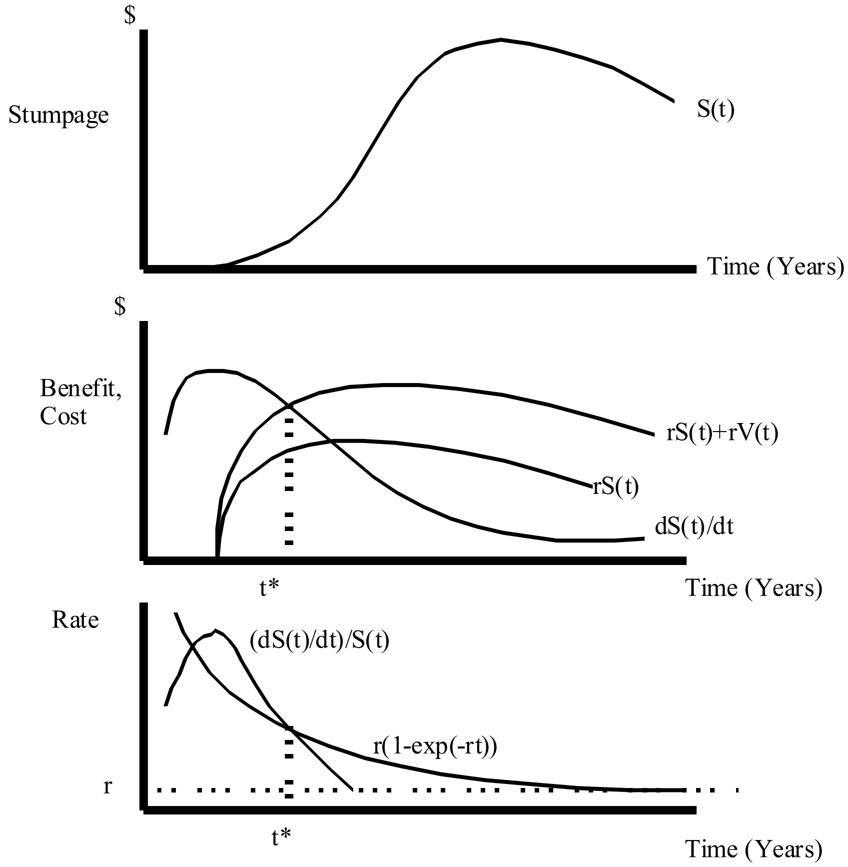


Figure 6: Calculating the MSY Rotation

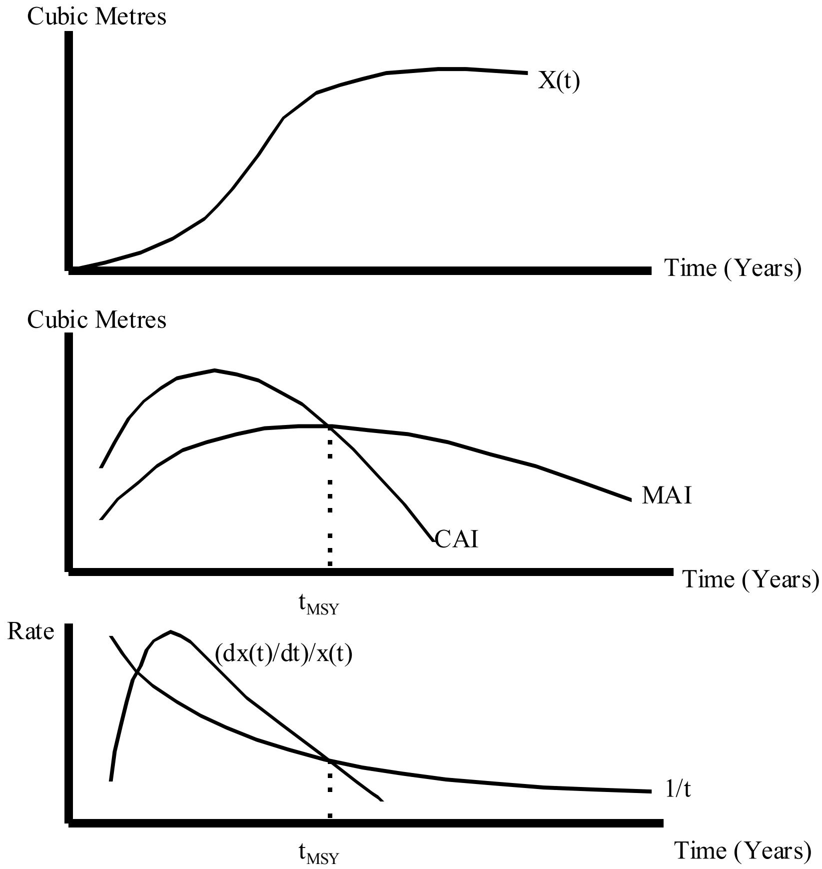


Figure 7: Comparison of MEY and MSY Rotations

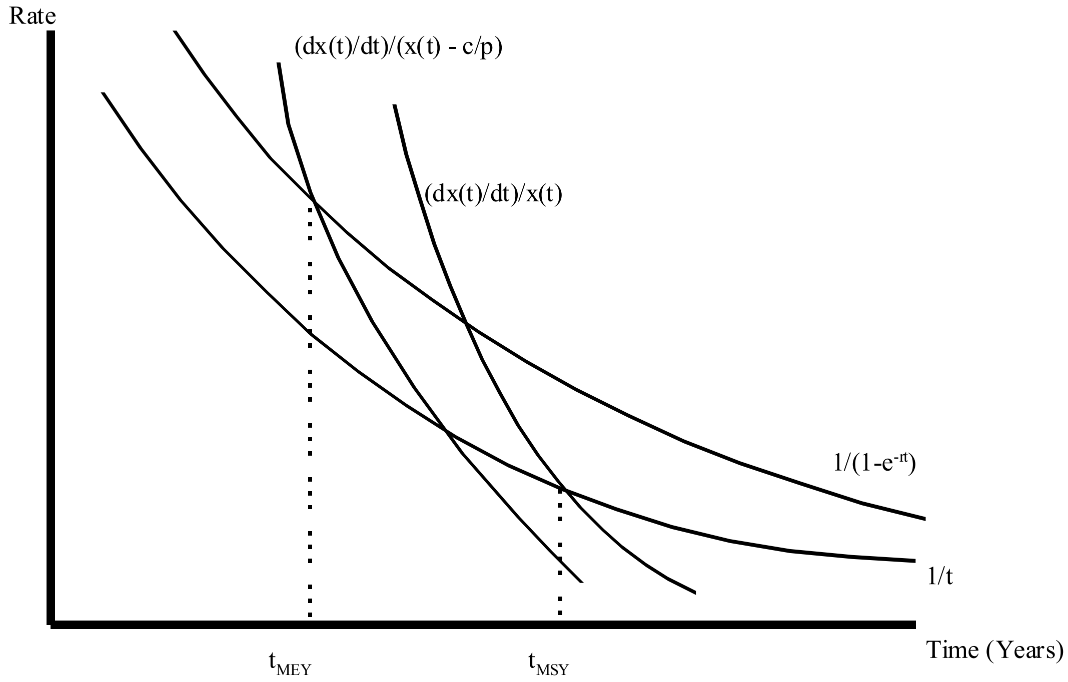


Figure 8: Production of Timber and Recreation Services from a Forest

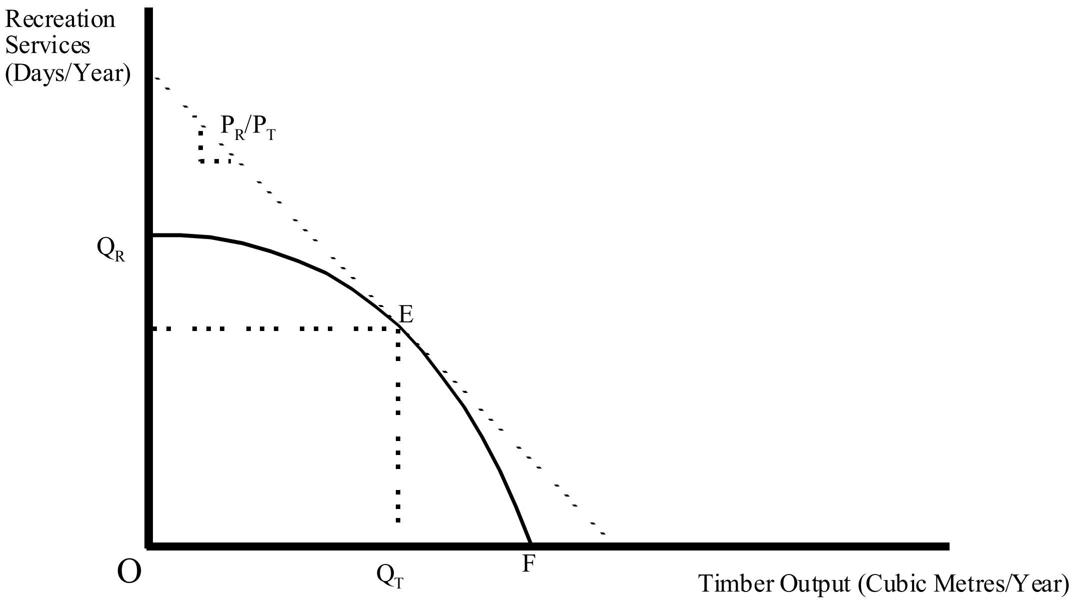


Figure 9: Output of the Forest in the Single Use Case

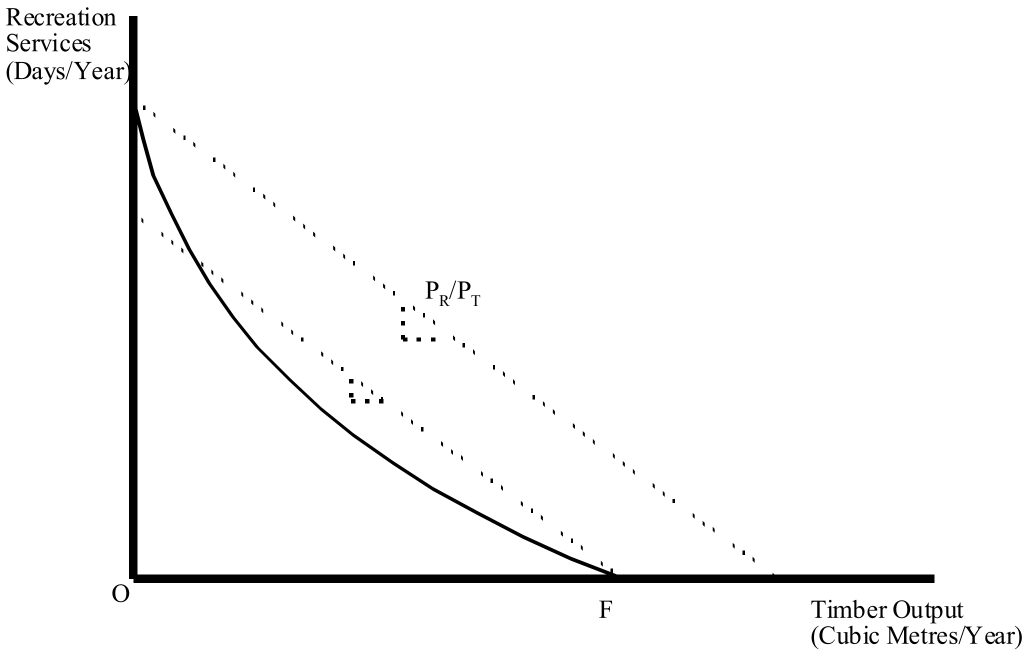


Figure 10: Deciding Whether the Forest Should Ever Be Cut

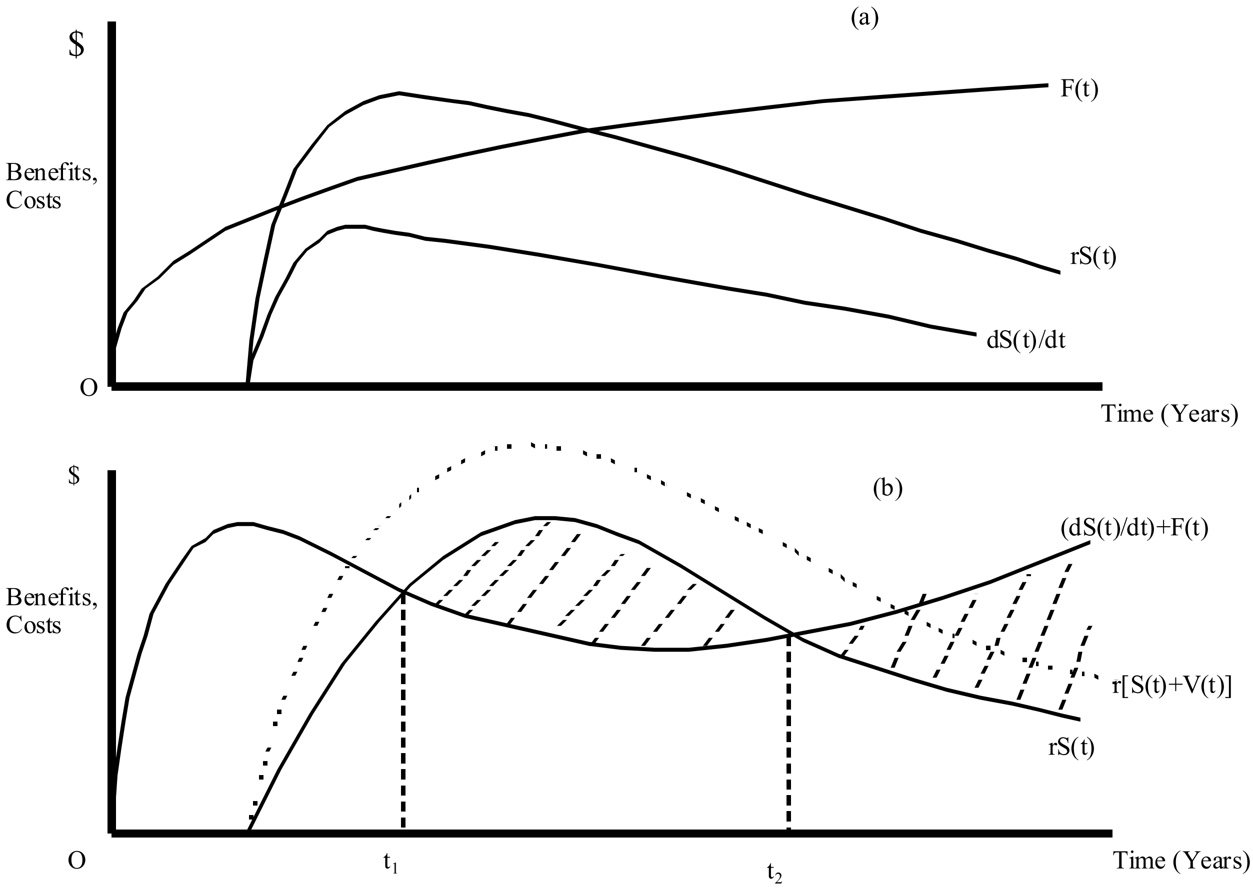


Figure 11: The Optimal Rotation Taking Non-timber Benefits and the Value of the Standing Forest into Account